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RESPONSES OF ALEWIFE AND GIZZARD SHAD TO FLASHING LIGHT

Report No 82-442-K

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ABSTRACT

Responses of gizzard shad and alewife to flashing metal halide, incandescent and strobe light sources were investigated under laboratory conditions. Overall, the strobe light source was the most effective fish excluder especially at flash frequencies exceeding 200 flashes/minute. Fish avoidance of strobe light appears to be related to the rapid discharge characteristic of each flash. Flashing incandescent and metal halide light types do not appear as promising as strobe light in a fish diversion scheme.

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To Mr. F.J. Kee
Director of Research

RESPONSE OF ALEWIFE AND GIZZARD SHAD TO FLASHING LIGHT

1.0 INTRODUCTION

Both laboratory and field work have indicated the potential of using strobe light alone or as part of a fish exclusion scheme Ontario Hydro Research Division Report (OHRDR No 81-190-K, 81-61-K, 82-156-K). Fish show strong avoidance of this light source and, are repelled by low light levels. Fish avoidance of strobe lights appears to be related to the flash rate, with marked avoidance occurring when flash rate exceeds 200 flashes/minute (OHRDR No 79-104-K, 82-305-K). If fish repulsion is primarily a function of light flashing (beyond a certain rate), then light types other than strobe may show promise in fish diversion schemes. Information on effectiveness of flashing lights is of particular importance since there are concerns about technical problems associated with strobes such as bulb life. The objective of this study is to determine the responses of fish to different flashing lights. Preliminary work on alewife (Alosa pseudoharengus) has been presented elsewhere (OHRDR No 82-305-K) and will be summarized in this report.

2.0 MATERIALS AND METHODS

2.1 Species Investigated

Research was conducted on gizzard shad (Dorosoma cepedianum) and alewife (Alosa pseudoharengus). Adult shad, ranging in size from approximately 25 to 40 cm, were collected by electroshocking in the winter of 1981, at both Burce GS 'A' and Pickering GS. Alewife were collected primarily at night at Pickering GS during the spring and summer of 1981. Alewife length varied from approximately 11 to 16 cm.

Several days prior to experimentation, the fish were held in 3.6 m circular pools under a natural photoperiod of 10 to 14 h of light. Water temperature ranged from approximately 7.0 to 9.5°C in the gizzard shad tests, and was slightly warmer in the alewife experiments (9.5 to 13.0°C). Both species were not fed during the course of the experiments.

2.2 Types of Light

Incandescent, metal halide and strobe light sources were used in this investigation. The spectral composition of both incandescent and metal halide (phosphore coated) was similar, showing a high proportion of energy in the orange and red regions of the light spectrum (Figure 1). The spectral composition of the strobe light source varied little over the visible light range, with slightly higher energy in the blue-green region of spectrum. Since earlier work indicated that alewife, and particularly shad, responded negatively to red light (OHRDR No 78-516-K), it was considered possible that fish may avoid flashing incandescent and metal halide light to a greater extent than strobe light. In addition, tests were performed for shad, using a blue-filtered incandescent light source. The blue-filter transmitted light primarily in the 400 to 500 mm range .

Flashing incandescent and metal halide sources were produced by rotating a disc with six slot openings (1.0 cm x 4 cm) over the light bulb (Figure 2). By varying the speed of the disc and the number of slot openings, flash frequencies ranging from 60 to 1000 flashes/minute could be achieved. The discharge flash produced by the rotating disc (either incandescent or metal halide sources) approximated a bell shape curve, the duration of which was several orders of magnitude longer than that of the strobe (Figure 3). For example, at a flash rate of 200 flashes/minute, peak intensity of the incandescent source was achieved 105 ms after discharge, approximately 1300 times slower than that of the strobe. It is worth noting that these differences (in magnitude) between light types in flash duration were not obvious (human vision).

2.3 Experimental Design

Short term experiments were used to determine the initial response of alewife to light (strobe, incandescent, metal halide) and to assess the role of flash frequency in eliciting a response. Experiments were conducted in a 3.6 m circular tank which was divided equally into three areas, each approximately 3.3 m^2. Description of the tank and experimental procedures are given elsewhere (OHRDR No 78-516-K, 82-305-K). In the design, one chamber was illuminated with the light source which was the sole source of illumination during the testing period. For each experiment the light source was projected downwards in the tank producing concentric zones of varying light intensities (Figure 4). Both incandescent and metal halide light sources were calibrated to approximate light levels produced by the strobe light source. Light intensities, measured as illuminance (lux) and quantum flux ($\mu E \cdot m^{-2} \cdot s^{-1}$) with a photometer/quantum meter (L1-185), were similar among light types and ranged from

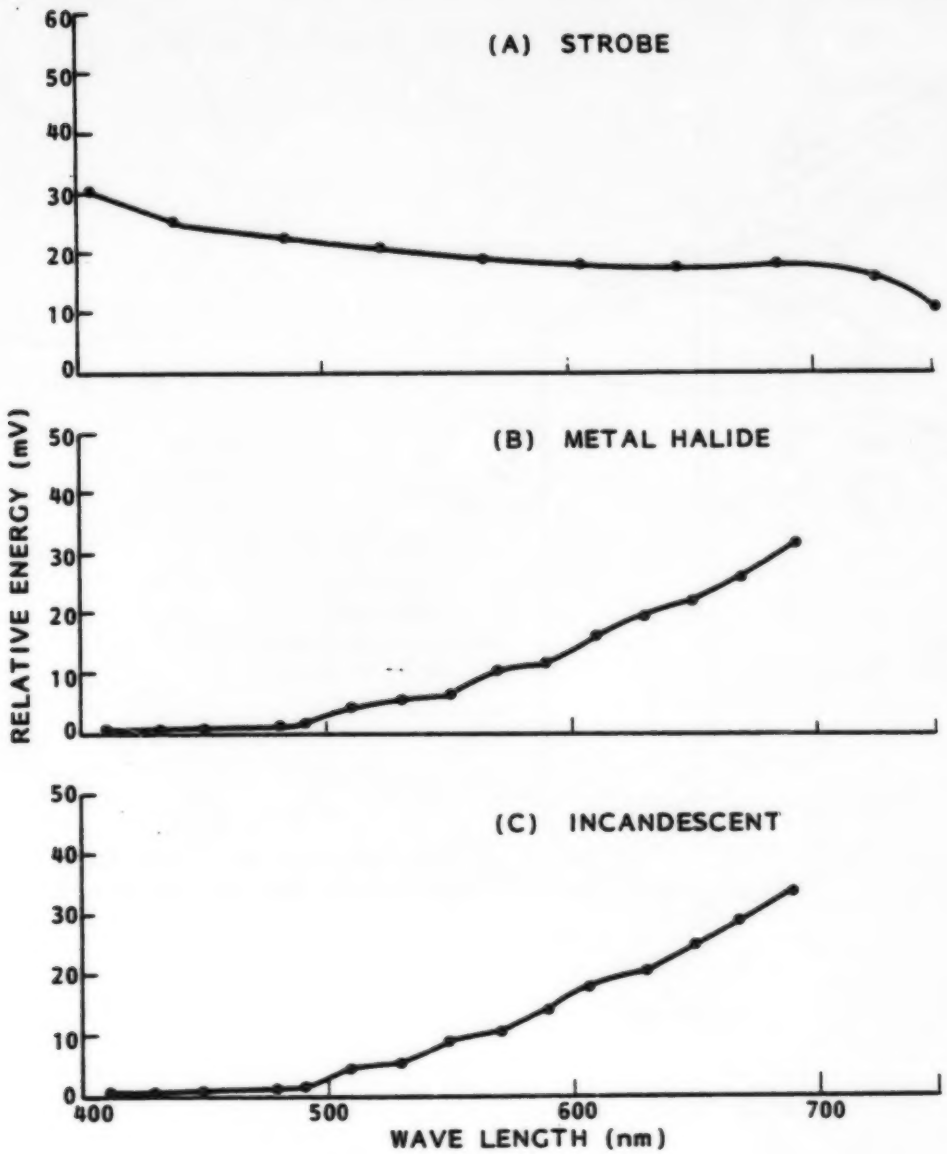

FIGURE 1

SPECTRAL DISTRIBUTION CURVES FOR
A. STROBE: B. METAL HALIDE AND C. INCANDESCENT LIGHT SOURCES

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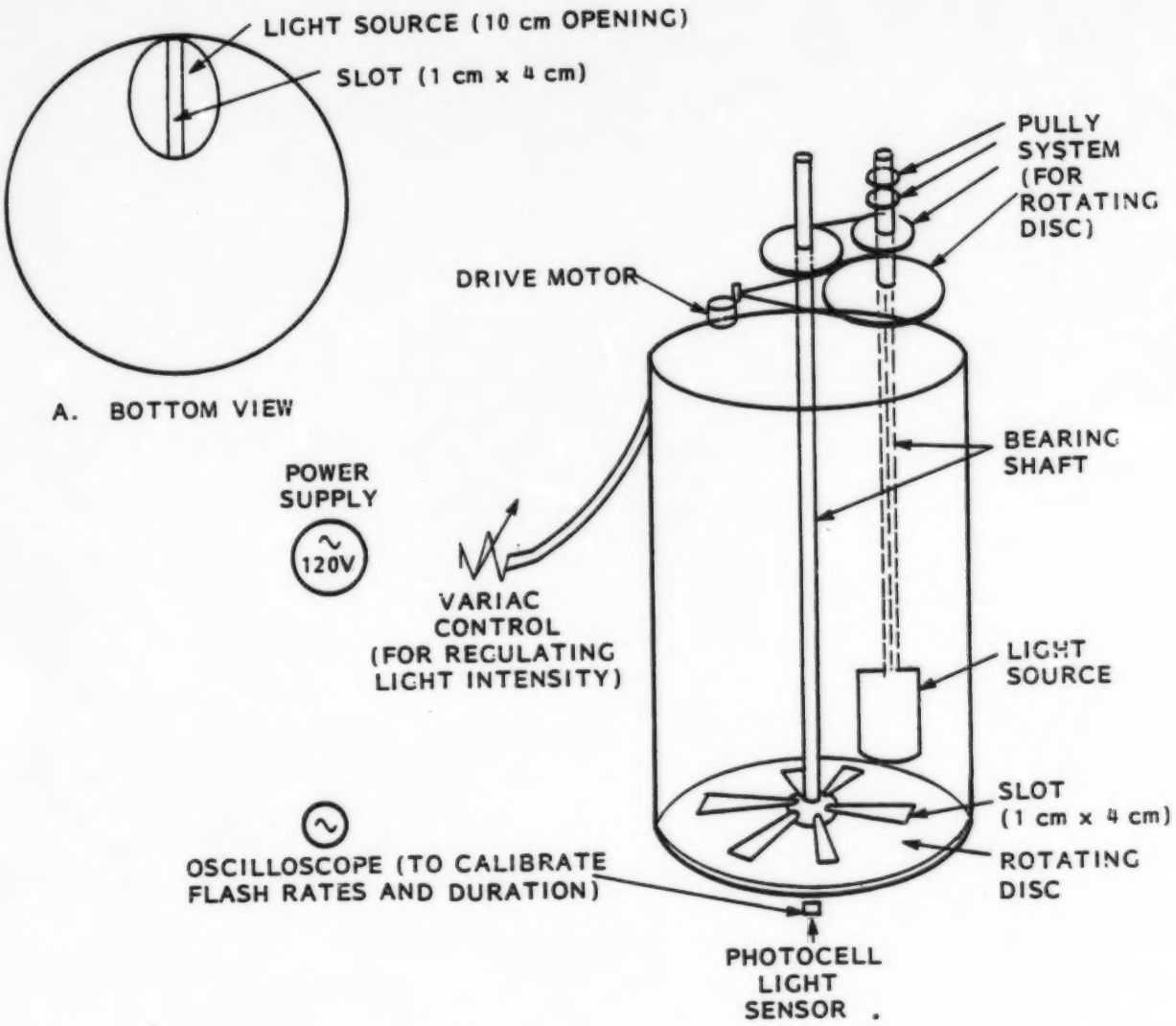

SCALE : 5 cm = 30 cm

FIGURE 2

DESIGN OF FLASHING LIGHT HOUSING
A. BOTTOM VIEW AND B. SIDE VIEW

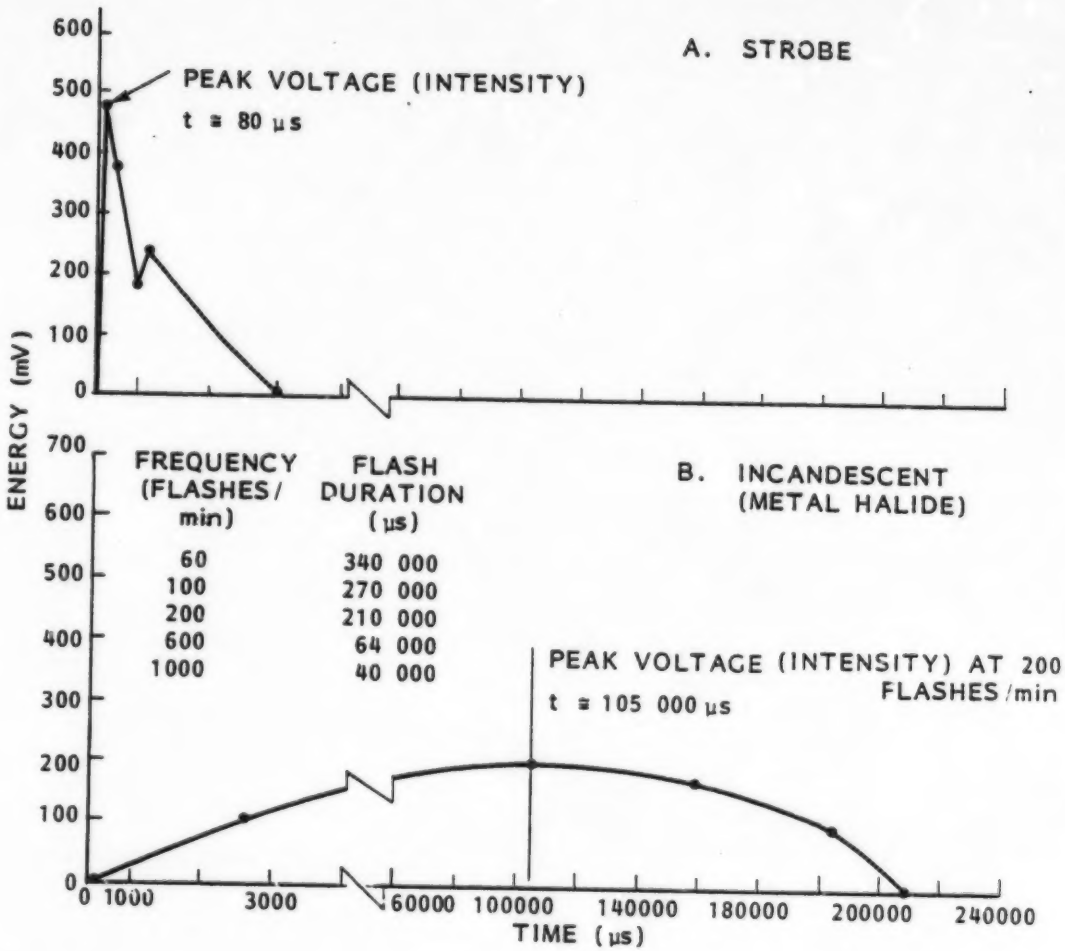

FIGURE 3

COMPARISON OF FLASH DURATION BETWEEN
A. STROBE AND B. INCANDESCENT (OR METAL HALIDE) LIGHT SOURCE

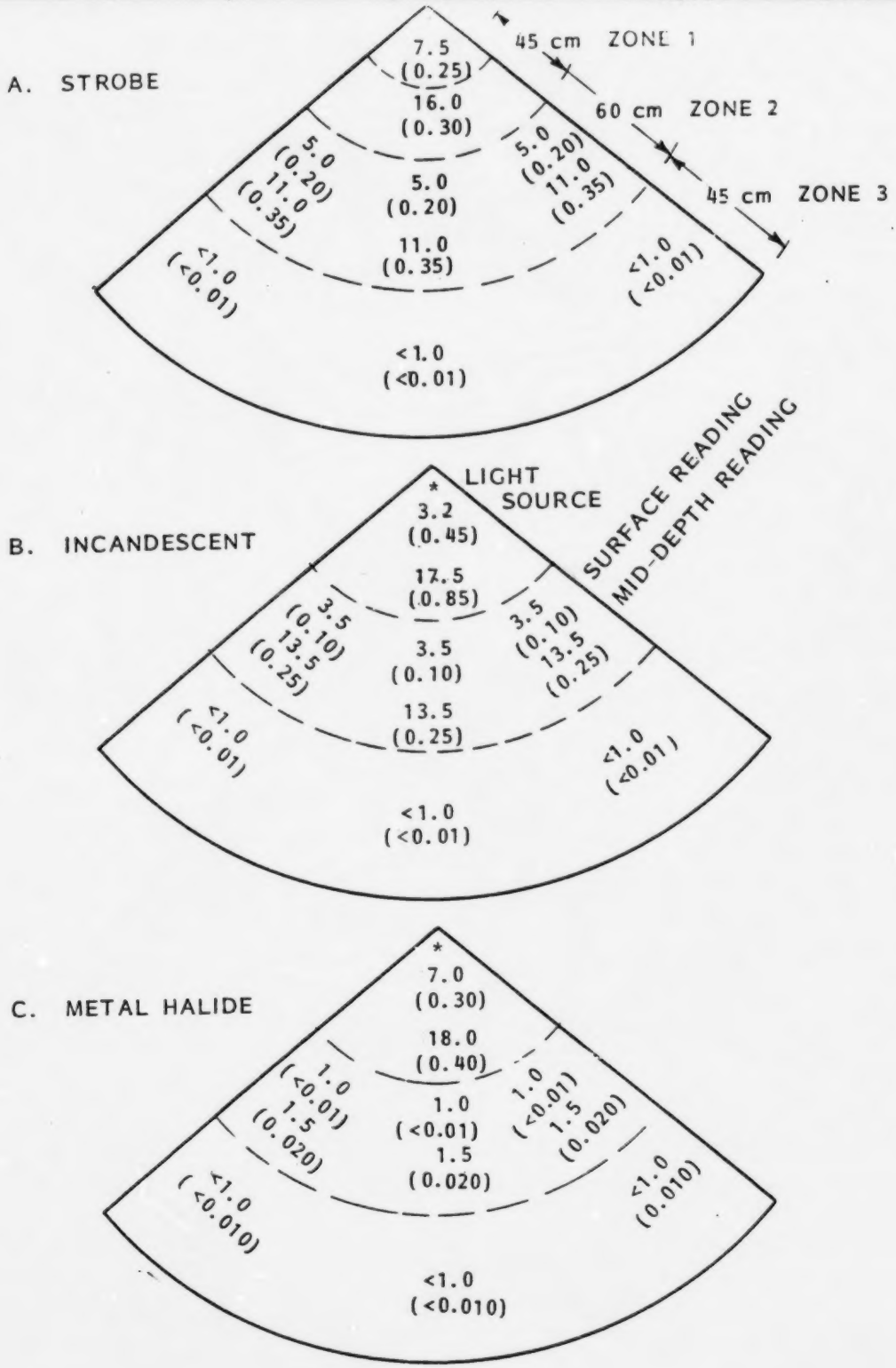

FIGURE 4

APPROXIMATE LIGHT INTENSITIES MEASURED AS ILLUMINANCE (LUX) AND QUANTUM FLUX ($\mu E.m^{-2}.s^{-1}$ IN BRACKETS) FOR A. STROBE LIGHT B. INCANDESCENT AND C. METAL HALIDE LIGHT SOURCES

16 to 18[1] lux (<1.0 $\mu E \cdot m^{-2} \cdot s^{-1}$) near the light source to less than 1 lux (<0.01 $\mu E \cdot m^{-2} \cdot s^{-1}$) at the edge of the pool (Figure 4). This area of low level light (<1 lux, <0.01 $\mu E \cdot m^{-2} \cdot s^{-1}$, approximately 51% of the area of the tank) provided a refuge area for fish which may be sensitive to the higher light levels. Light intensities estimated close to the light source (within 45 cm) were somewhat higher for both strobe and incandescent light sources than for the metal halide light. In the blue-filtered incandescent tests, light output was reduced approximately 10%. The illuminated chamber had no influence on the other two chambers which were in darkness during the testing period.

Experimental illumination periods were 5 minutes for alewife (OHRDR No 82-305-K), and both 5 and 15 minutes in the gizzard shad tests. Ten replicates, were performed at the following flash frequencies: 60, 100, 200, 600 and 1000 flashes/minute. Each replicate consisted of 15 shad or 50 alewife. Emphasis was placed on using different fish for each test. After each illumination period, the chutes which divided the chambers were closed and the number of fish in each chamber recorded. Observations were also made, both prior to, and following closing of the chutes on the approximate distribution of alewife in all chambers relative to the light source. Control tests (n = 104 for alewife, n = 400 for shad) were conducted over similar time periods (5, 15 minutes, no light source) and were alternated with experimental tests to reduce any temporal bias. Fewer controls in the alewife tests were due to fish availability problems.

3.0 RESULTS AND DISCUSSION

3.1 Alewife

The effectiveness of incandescent, metal halide and strobe light sources in reducing alewife encounters over various flashing rates is shown in Figure 5. Overall, strobe light appeared to be the most effective fish excluder, followed by incandescent and metal halide light sources. Reductions with strobe light were particularly noticeable at the higher flash rates. Mean number of alewife recorded in the metal halide light chamber at a flash rate of 600 flashes/minute exceeded that of the control, suggesting an attraction response.

Analysis of variance (ANOVA) was used to compare the effectiveness of each light type relative to the controls for each flash frequency (Table I). With the exception of a flash rate of 60, results indicated that strobe light reduced alewife encounters

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[1] Because of probe saturation, the stobe light measurements close to the light source are probably underestimated.

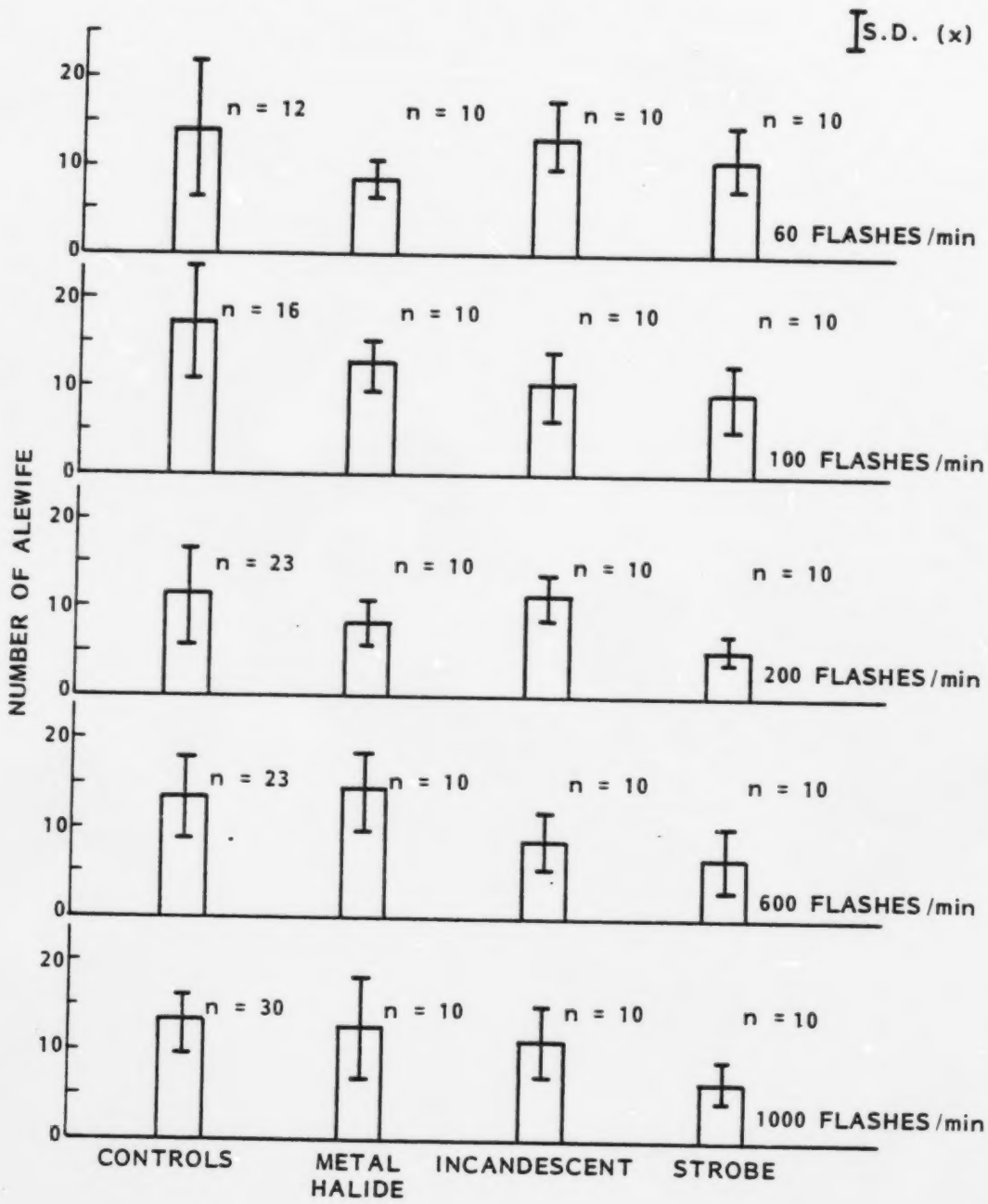

FIGURE 5

COMPARISON OF STROBE, METAL HALIDE AND INCANDESCENT LIGHT TYPES IN EXCLUDING ALEWIFE OVER VARIOUS FLASH FREQUENCIES

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TABLE I

ANOVA (ONE-WAY) AND MULTIPLE RANGE TEST (SNK) COMPARING THE EFFECTIVENESS OF STROBE, INCANDESCENT AND METAL HALIDE LIGHT SOURCES RELATIVE TO CONTROL TESTS

Flash Frequency (flashes/minute)	df	F-test	Multiple Range (Fish Numbers) lowest → highest
60	3,37	1.9	--
100	3,42	9.0*	S IN MH C
200	3,49	6.2*	S MH IN C
600	3,49	8.5*	S IN C MH
1000	3,56	6.4*	S MH IN C

S = strobe

IN = incandescent

MH = metal halide

C = control

* $p < 0.5$.

TABLE II

ANOVA (ONE-WAY) AND MULTIPLE RANGE TEST (SNK) COMPARING THE ROLE OF FLASH RATE IN ELICITING A FISH AVOIDANCE RESPONSE

Light Type	df	F-test	Multiple Range* (effectiveness) lowest → highest
Strobe	4,45	9.8	60, 100, 1000, 600, 200 Flash Rate 10 | 9.7 | 6.7 6.7 | 5.4 No Alewife

* Dotted line indicates high variability.

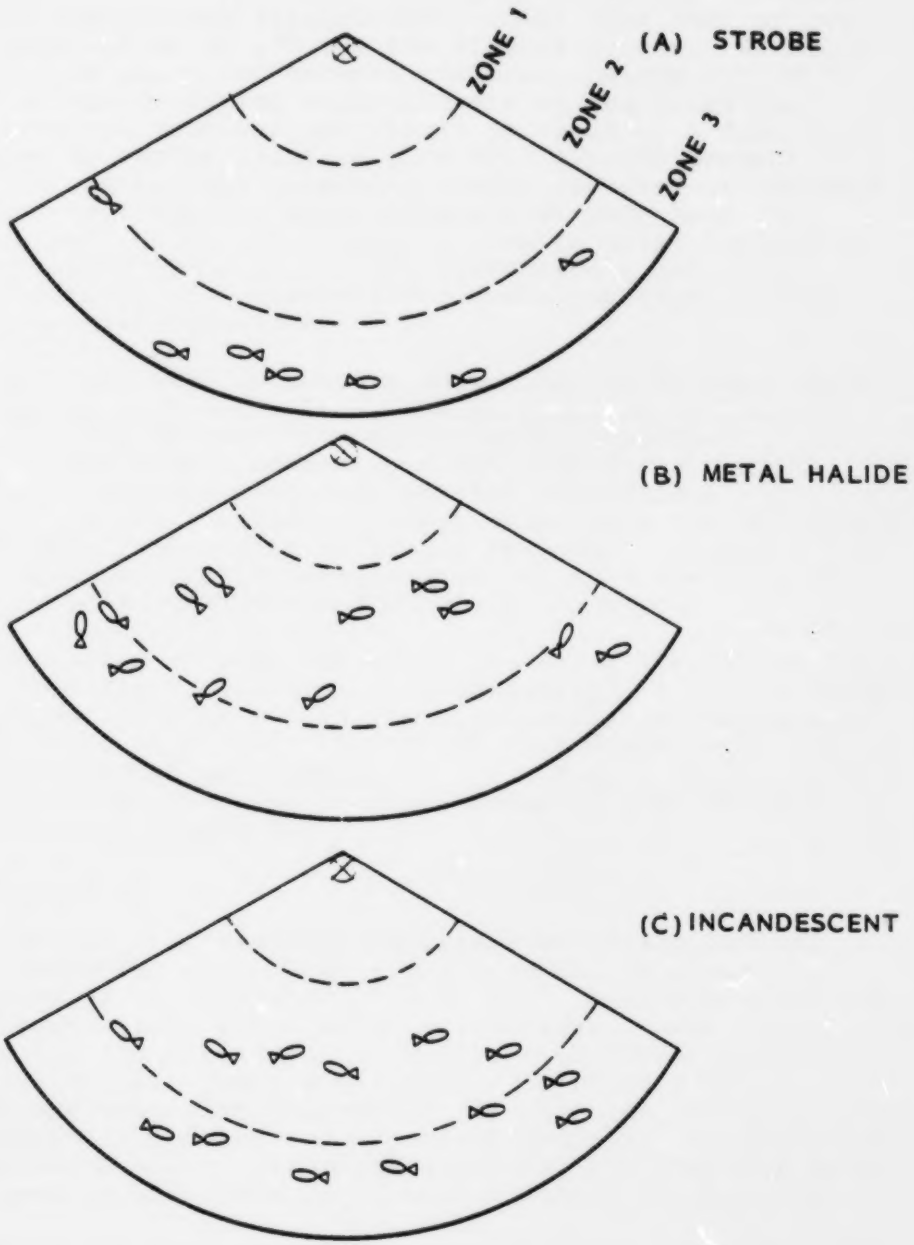

FIGURE 6

APPROXIMATE POSITION AND ORIENTATION OF ALEWIFE IN RESPONSE TO A. STROBE, B. METAL HALIDE AND C. INCANDESCENT LIGHT SOURCES

significantly compared to control numbers, suggesting an avoidance response. The number of alewife recorded in the incandescent (IN) lit chamber was significantly lower than that of the control at flash rates of 100 and 600 flashes/minute. No significant difference was noted between the metal halide lit (M H) chamber and occupancy during control tests on any occasion. Visual observations provided additional evidence of a fish avoidance response to strobe light (Figure 6). Alewife present in the strobe lit chamber was generally always recorded at the edge of the light zone (Zone 3), where intensities were less than 1 lux ($0.01\ \mu E \cdot m^{-2} \cdot s^{-1}$). In contrast, alewife were observed at higher light levels (Zone 2) in both incandescent and metal halide lit chambers, and orientation towards the light source was noted on several occasions.

A two-way ANOVA was used to compare effectiveness between light types in reducing fish encounters, and also assess the importance of flash rate in eliciting an avoidance response (Appendix A). The F-test comparing flash rate for all light types (all light results combined) was not significant ($F_{4,135} = 2.3$, $p > .05$), indicating that flash rate did not play a major role in eliciting a fish avoidance response. However, the interaction term was significant, suggesting that the rate may not be similar in effectiveness for all light types.

Overall, mean number of fish was noted lowest in the strobe lit chamber ($\bar{x} = 7.7$ fish), followed by incandescent ($\bar{x} = 10.9$ fish) and metal halide light ($\bar{x} = 11.3$ fish) sources. An analysis of the strobe results separately, indicated that flash rate significantly affected performance ($F_{4,45} = 9.8$, $p < 0.05$), with strongest avoidance occurring at flash rates of 200, 600 and 1000 flashes/minute (Table II).

3.2. Gizzard Shad

The mean number of shad recorded in experimental and control tests (alternated for each light type) is shown in Figure 7. With the exception of strobe (200, 600, 1000 flashes/minute) and some incandescent light tests (high flash rates), most light combinations did not significantly reduce fish number relative to the control tests. There also appears to be no evidence of attraction since mean fish numbers in the experimental tests rarely exceeded that of any corresponding control. Avoidance of incandescent light was expected since earlier work has indicated that shad avoided this light source (OHRDR No 78-516-K).

A two-way ANOVA was used to compare statistically the effectiveness of light types (adjusted for controls) in excluding shad, and the role of flash rate in eliciting a shad avoidance response (Appendix C). Analysis was done separately for each illumination period. The F-tests comparing light types were signficant (5 minute test $F_{3,179} = 11.06$, $p < 0.01$; 15 minute

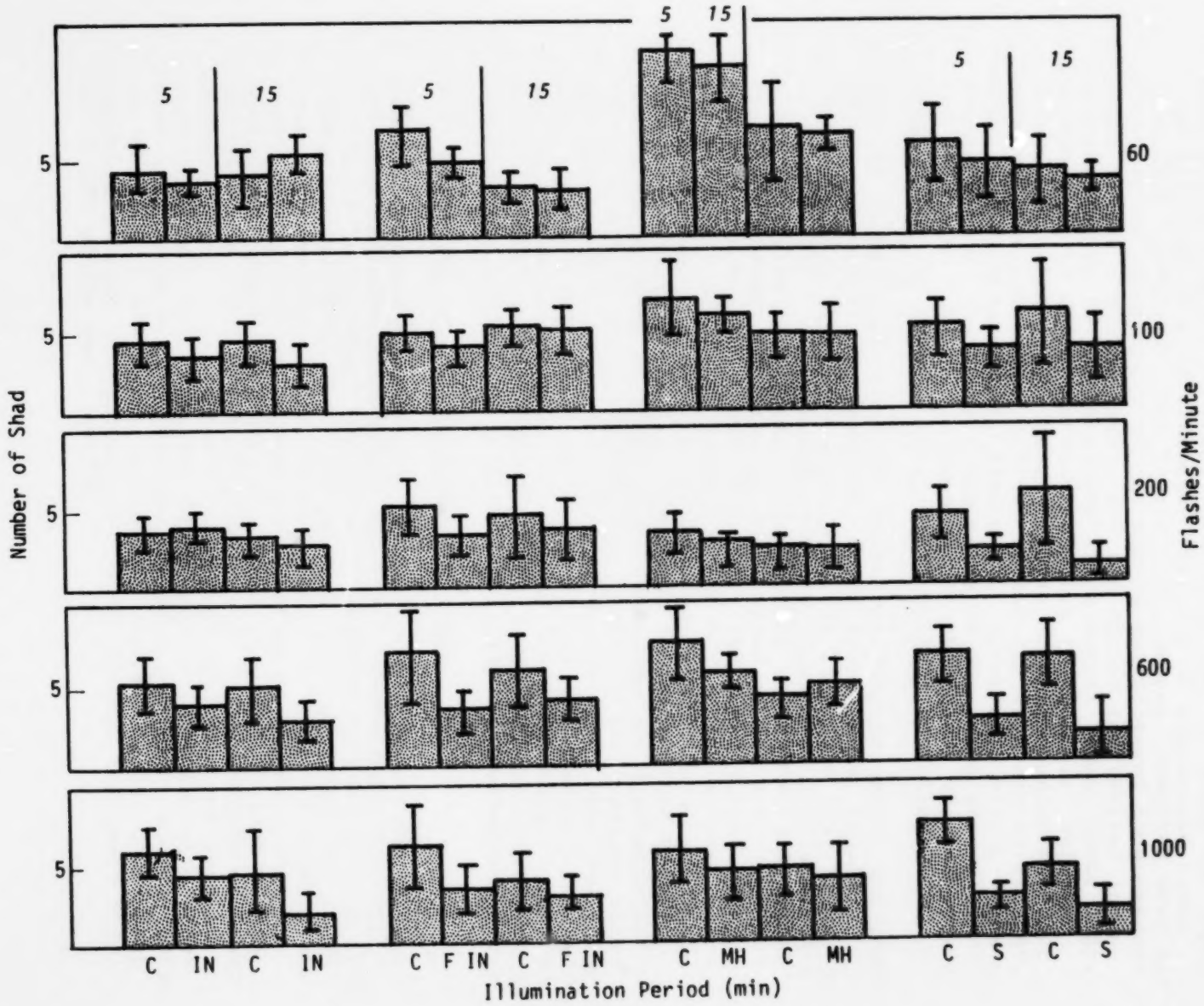

FIGURE 7
COMPARISON OF STROBE, METAL HALIDE AND INCANDESCENT LIGHT SOURCES IN EXCLUDING SHAD OVER VARIOUS FLASH FREQUENCIES
(C=CONTROL, IN-INCANDESCENT, F IN-FILTERED INCANDESCENT, S-STROBE, M.H.-METAL HALIDE)

test $F_{3,179} = 4.98$, $p < 0.01$) indicating that at least one light type differed in effectiveness. Results of a multiple range test (SNK) indicated that lowest fish numbers (combined over all flash rates) were recorded for strobe and filtered incandescent light in the 5 minute tests, and for strobe and (white) incandescent lights in the 15 minute illumination tests (Table III). Differences in effectiveness (relative to controls) between strobe and other light types are even more pronounced when one compares results (fish numbers) at the higher flash rates (200, 600, 1000 flashes/minute, Figure 7). After a 15 minute illumination period, there was a reduction of 70% using strobe light and 43% using (white) incandescent in the number of shad occurring in the lit chamber relative to control conditions.

For all light types combined, flash rate significantly influenced the number of fish recorded in the experimental chambers (5 minute test ($F_{4,179} = 4.95$, $p < 0.01$; 15 minute test $F_{4,179} = 3.16$, $p < 0.05$). A follow-up multiple range test indicated that after 5 minutes of illumination, highest reduction (all light results combined) occurred at flash rates of 600 and 1000 flashes/minute (Table IV). With increased illumination (15 minutes), all flash rates (except 60 flashes/minute) appeared equally effective in reducing fish numbers. An analysis of the strobe results separately indicated that marked avoidance occurred at flash rates exceeding 200 flashes/minute ($F_{4,90} = 8.9$, $p < 0.01$, Appendix D). Visual observations also suggested greater fish avoidance of strobe light than the other light types. Shad observed in the strobe lit chamber were generally always recorded at the edge of the light zone (Figure 4) where intensities were lowest. This behaviour was not always observed for shad in response to both metal halide and incandescent light sources.

3.3 Responses of Fish to Flashing Lights

Results indicate that strobe light is a more effective alewife and shad excluder than either flashing incandescent and metal halide light sources. Results also support earlier work on shad (OHRDR No 79-104-K) where marked avoidance occurred when flash rate exceeded 200 flashes/minute. Alewife were not effectively repelled by flashing incandescent and metal halide light sources, although avoidance did occur for shad in some of the incandescent light tests (Figures 5 and 7). Avoidance of incandescent light (blue, white) by shad was probably not totally related to the unit flashing since earlier work had also shown that shad avoid even a constant incandescent light source (OHRDR No 78-516-K). Similarly, Fields and Fingers (1954) found that salmon avoidance of incandescent light was not increased when the light source was flashing.

TABLE III

MULTIPLE RANGE TEST (SNK) COMPARING THE EFFECTIVENESS OF VARIOUS LIGHT TYPES IN EXCLUDING FISH

Illumination Period (Min)	Multiple Ranking effectiveness lowest → highest				
5	0.88 Incandescent	0.84 Metal Halide	0.68 Blue Incandescent	0.57 Strobe	No of Fish* light type
15	1.2 Metal Halide	1.0 Blue Incandescent	0.84 Incandescent	0.59 Strobe	No of Fish light type

* ratio of $\frac{\text{\#fish exp}}{\text{\#fish controls}}$ for each light type

TABLE IV

MULTIPLE RANGE TEST (SNK) COMPARING THE ROLE OF FLASH RATE IN EXCLUDING FISH

Illumination Period (minutes)	Multiple Ranking effectiveness lowest → highest					
5	0.83	0.83	0.81	0.64	0.62	No of Fish*
	200	60	100	1000	600	Flash Rate (flashes/ minute)
15	1.3	0.86	0.82	0.81	0.75	No of Fish
	60	100	200	1000	600	Flash Rate (flashes/ minute)

* Ratio of No $\frac{\text{Fish in Exp}}{\text{Fish in Controls}}$ for each light type.

Recent laboratory evidence has indicated that fish avoidance of strobe light is related to the flash characteristics of the strobe source (OHRDR No 82-310-K). Strobe light flash reaches peak intensity approximately 80 μ (less than 100 μs) after discharge and declines exponentially over a 3 to 5 ms period. Research on shad has shown that an increase in flash duration results in less of a fish avoidance response (OHRDR No 82-310-K). In this investigation, the flash durations of incandescent and metal halide light sources were several orders of magnitude longer than that of strobe light (Figure 3). Similarly, the duration of the flashing incandescent light source used by Fields and Finger (proven not to be effective) (1954) was also quite long, ranging from approximately 120 to 500 ms (calculated). Flashing lights of long flash duration probably have limited use in fish diversion studies, since little or no avoidance was demonstrated using metal halide or incandescent light sources.

It is noteworthy the similarity between the discharge curves of strobe light used in the investigation with those produced by bioluminescent organisms and their possible functions. Several marine organisms (invertebrates, algae, fish) produce a discharge similar in shape to that of a strobe (although duration is longer) to repel predators, and to aid in the capture of prey (Morin et al 1975, Herring 1978, Morin, pers comm). The more continuous the light discharge or the longer the flash, the less advantageous it is to the luminescent organism as a defence mechanism (Buck, per comm). Flash discharges of some bioluminescent organisms appear similar in shape to that produced by the flashing light unit used in our fish tests. These light discharges appear to have primarily intra-specific functions such as sexual recognition, courtship display and swarming or schooling rather than repulsion (Herring 1978).

4.0 SUMMARY

1. The responses of alewife and gizzard shad to flashing incandescent, metal halide, and strobe light sources were determined.

2. Strobe light at flash rates exceeding 200 flashes/minute was the most effective light source in eliciting fish avoidance. Flashing incandescent and metal halide light sources do not appear as promising as strobe light in fish diversion schemes, as little or no avoidance of these lights was observed.

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REFERENCES

1. Buck, J. 1982. National Institute of Health. Personal Communication. Bethesda, Maryland, USA.

2. Fields, P.E. and Fingers, G.L. 1956. "The Effectiveness of Constant and Intermittently Flashing Light Barriers in Guiding Young Silver Salmon". University of Washington Technical Report 22.

3. Herring, P.S. 1978. (Ed) Bioluminescence in Action, Academic Press, 570 pp.

4. Ontario Hydro Research Division Report No 78-516-K. "Responses of Fish to Light". Patrick, P.H. 1978.

5. Ontario Hydro Research Division Report No 82-310-K. "Responses of Gizzard Shad (Dorosoma Cepedianum) to Different Flash Characteristics of Strobe Light". Patrick, P.H. 1982.

6. Ontario Hydro Research Division Report No 79-104-K. "Responses of Gizzard Shad to Strobe Light". Patrick, P.H. 1979.

7. Ontario Hydro Research Division Report No 80-156-K. "Effectiveness of a Chain-Net Strobe Light Shad Exclusion Scheme". Patrick, P.H. 1980.

8. Ontario Hydro Research Division Report No 81-190-K. "Responses of Fish to Diversion Barriers". Patrick, P.H. 1981.

9. Ontario Hydro Research Division Progress Report No 82-305-K. "Response of Alewife to Flashing Light". Patrick, P.H. 1982.

10. Ontario Hydro Research Division Report No 81-61-K. "American Eel Response to White Strobe Light - R.H. Saunders". Sheehan, R.W. and Sim B. 1981.

11. Ontario Hydro Research Division Report No E81-75-H. "Extending the Flash Duration of Strobes". Staelter, M. 1981.

12. Ontario Hydro Research Division Report No 82-156-K. "Use of Filtered Mercury Vapour Lights in Association with a Modified Fish Handling Pump at Nanticoke GS". Haymes, G.T. 1982.

13. Morin, J.G., Harrington, A., Nealson, K., Krieger, N., Baldwin, T.O., and Hastings, J.W. 1975. "Light for all Reasons and Versatility in the Behavioural Repertoire of the Flashlight Fish". Science 190-74-76.

14. Morin, J.G., Personal Communication. University of Southern California at Los Angeles.

APPENDIX A

EXPERIMENTAL TREATMENT DATA
(NUMBER OF ALEWIFE IN EXPERIMENTAL ZONE)

(a) Metal Halide Light

Flash Rate / Rep	1	2	3	4	5	6	7	8	9	10
0060	05	08	12	07	11	09	06	08	10	09
0100	10	15	11	17	18	12	09	17	09	09
0200	12	10	06	05	10	11	08	05	10	05
0600	18	21	27	15	12	11	10	10	13	11
1000	24	17	14	15	14	06	12	10	08	05

(b) Strobe Light

Flash Rate / Rep	1	2	3	4	5	6	7	8	9	10
0600	09	09	15	09	13	08	12	06	11	08
0100	13	10	16	14	07	06	07	01	09	14
0200	06	06	05	03	07	03	08	05	04	07
0600	03	13	07	05	05	09	08	01	10	06
1000	06	07	05	03	11	08	09	07	07	04

(c) Incandescent Light

Flash Rate / Rep	1	2	3	4	5	6	7	8	9	10
0600	12	20	07	14	10	17	10	13	15	17
0100	14	10	16	10	10	15	05	04	09	08
0200	16	09	07	12	10	10	09	12	13	13
0600	10	11	10	09	09	09	13	07	00	09
1000	06	07	14	15	08	11	09	08	17	16

APPENDIX A

ANOVA (TWO-WAY) COMPARING THE EFFECTIVENESS BETWEEN STROBE, METAL HALIDE AND INCANDESCENT LIGHT TYPES IN REDUCING FISH NUMBERS

Comparison	Degress of Freedom					F-test Flash Rate (FR)	Interaction (I)
	L	FR	I	T	Light (L)		
(Light-type, strobe incandescent, metal halide.) Flash frequency (60, 100, 200, 600 and 1000 flashes/minute).	2	4	8	149	14.4*	2.3	4.5*

---

* $p < 0.05$

Mean number of fish (highest → lowest)	Metal Halide	Incandescent	Strobe	No Alewife
	11.3	10.9	7.7	

APPENDIX A

CONTROL DATA

Flash Rate	Rep 1	Rep 2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
60	25	11	6	23	13	29	7	4	12	12	11	19																		
100	13	28	11	16	16	23	21	14	18	18	29	13	14	24	13	17														
200	16	32	16	23	10	11	8	6	10	12	12	12	10	9	12	7	10	13	11	10	13	7	11							
600	12	11	18	11	19	16	6	16	14	20	4	8	7	7	17	14	14	14	13	16	14	19	16							
1000	11	18	14	10	18	15	15	21	20	13	16	17	14	7	13	14	8	13	17	17	11	10	11	6	13	9	13	18	6	9

APPENDIX B

NUMBER OF SHAD RECORDED IN CONTROL AND EXPERIMENTAL TESTS

(i) Incandescent - 5 minute illumination

60		100		200		600		1000	
Control	Experi-mental	Control	Experi-mental	Control	Experi-mental	Control	Experi-mental	Control	Experi-mental
4	4	4	3	5	5	5	4	6	4
5	5	4	2	4	5	3	2	8	6
6	5	2	2	7	5	5	3	8	3
3	2	4	6	1	2	4	6	5	4
4	4	8	6	3	2	9	4	6	3
8	3	4	3	2	3	6	5	5	3
4	4	3	2	2	3	7	3	8	6
4	4	5	4	6	5	4	3	3	3
3	3	5	4	3	5	8	7	5	3
5	4	7	5	5	4	6	5	6	8
$\bar{X}$ 4.5	3.8	4.6	3.7	3.8	3.9	5.7	4.2	6.0	4.3
SD (x) 1.5	0.9	1.8	1.6	1.9	1.3	1.9	1.5	1.6	1.8

APPENDIX B

NUMBER OF SHAD RECORDED IN CONTROL AND EXPERIMENTAL TESTS

(2) Incandescent - 15 minute illumination

60		100		200		600		1000	
Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
5	6	4	2	3	4	3	4	3	2
6	5	4	2	2	1	5	2	6	0
6	5	5	2	3	2	3	5	10	2
3	6	6	4	3	4	8	4	6	0
7	7	6	4	5	2	4	2	6	1
3	4	5	5	6	3	4	2	3	3
3	6	5	3	4	2	8	2	3	1
1	4	3	2	2	1	8	4	3	3
4	6	3	4	3	2	2	1	3	3
4	5	5	1	5	6	6	2	3	3
$\bar{X}$ 4.2	5.4	4.6	2.9	3.6	2.7	5.1	2.8	4.6	1.8
SD (x) 1.8	0.9	1.1	1.3	1.3	1.6	2.3	1.3	2.4	1.2

APPENDIX B

NUMBER OF SHAD RECORDED IN CONTROL AND EXPERIMENTAL TESTS

(3) Strobe - 5 minute illumination

60		100		200		600		1000	
Control	Experi-mental	Control	Experi-mental	Control	Experi-mental	Control	Experi-mental	Control	Experi-mental
3	1	7	3	6	0	5	3	5	1
7	7	8	4	7	3	8	5	8	4
8	5	8	5	3	2	6	2	6	2
6	5	3	3	3	3	6	3	5	2
4	3	6	4	3	5	9	4	8	2
5	5	5	4	7	2	5	2	9	4
6	5	3	3	3	0	9	4	9	3
9	7	4	4	5	2	7	3	7	3
8	6	4	3	3	1	8	3	8	3
3	2	6	6	6	3	4	2	7	2
$\bar{X}$ 5.9	4.6	5.4	3.9	4.6	2.1	6.7	3.1	7.2	2.6
SD (x) 2.1	2.0	1.9	1.0	1.8	1.5	1.8	1.0	1.5	1.0

APPENDIX B

NUMBER OF SHAD RECORDED IN CONTROL AND EXPERIMENTAL TESTS

(4) Strobe - 5 minute illumination

60		100		200		600		1000	
Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
7	5	5	3	3	2	6	0	4	0
7	4	4	7	9	0	4	3	4	1
5	5	4	3	11	4	8	0	3	2
5	3	1	2	12	1	7	1	4	4
3	3	12	1	2	2	6	1	5	3
2	2	9	7	6	0	8	3	4	0
3	3	9	5	3	1	7	1	5	3
3	4	8	3	3	0	5	0	7	1
4	3	5	3	4	2	5	8	6	0
1	3	6	3	6	2	10	1	2	2
$\bar{X}$ 4.0	3.5	6.3	3.7	5.9	1.4	6.6	1.8	4.4	1.6
SD (x) 2.0	0.9	3.2	2.0	3.6	1.3	1.8	2.4	1.4	1.4

APPENDIX B

NUMBER OF SHAD RECORDED IN CONTROL AND EXPERIMENTAL TESTS

(5) Metal Halide - 5 minute illumination

60		100		200		600		1000	
Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
9	5	10	9	5	4	8	5	8	4
11	8	11	8	4	4	7	5	8	7
10	11	9	8	4	4	9	5	6	8
8	5	9	7	4	4	8	6	7	6
6	9	9	6	2	2	6	5	2	3
10	8	4	4	1	1	12	7	5	3
9	9	5	5	6	2	6	8	5	4
12	10	7	5	5	4	5	4	8	5
10	9	5	4	3	4	8	6	6	2
7	7	6	6	3	2			4	3
$\bar{X}$ 9.2	8.1	7.5	6.2	2.6	3.0	7.7	5.7	5.9	4.5
SD (x) 1.8	2.0	2.4	1.7	1.5	1.1	2.1	1.2	2.0	1.0

APPENDIX B

NUMBER OF SHAD RECORDED IN CONTROL AND EXPERIMENTAL TESTS

(6) Metal Halide - 15 minute illumination

60		100		200		600		1000	
Control	Experi-mental	Control	Experi-mental	Control	Experi-mental	Control	Experi-mental	Control	Experi-mental
8	6	3	4	3	3	4	2	2	1
5	8	2	3	5	1	6	3	5	1
10	8	7	4	1	1	3	2	5	9
10	5	6	4	1	3	6	5	5	7
13	7	4	6	4	1	2	5	6	5
6	5	5	7	2	3	3	5	5	2
6	5	6	4	3	2	4	7	4	2
1	7	4	5	0	2	3	4	6	4
6	6	6	5	1	3	3	5	5	2
2	6	6	5	2	1	4	6	2	4
$\bar{X}$ 6.7	6.3	4.9	4.7	2.2	2.0	3.8	4.4	4.5	3.7
SD (x) 3.7	1.1	1.6	1.1	1.5	0.9	1.3	1.6	1.4	2.7

APPENDIX B

NUMBER OF SHAD RECORDED IN CONTROL AND EXPERIMENTAL TESTS

(7) Blue Filtered Incandescent - 5 minutes and 15 minutes (in brackets) illumination periods

60		100		200		600		1000	
Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental	Control	Experimental
5 (2)	3 (3)	5 (4)	5 (2)	3 (2)	3 (2)	11 (7)	4 (4)	8 (1)	1 (3)
8 (3)	5 (1)	5 (6)	2 (4)	7 (4)	3 (3)	5 (7)	2 (4)	7 (5)	2 (2)
5 (2)	4 (3)	- (5)	3 (4)	8 (4)	3 (6)	5 (5)	1 (4)	7 (3)	3 (3)
5 (4)	5 (2)	4 (4)	4 (7)	3 (6)	4 (5)	6 (3)	6 (4)	2 (1)	4 (4)
7 (2)	4 (2)	6 (6)	3 (6)	6 (3)	1 (0)	9 (5)	5 (5)	9 (7)	3 (2)
8 (4)	6 (3)	4 (5)	4 (4)	6 (3)	3 (5)	6 (6)	3 (6)	4 (1)	3 (3)
4 (2)	6 (3)	4 (5)	3 (6)	5 (8)	2 (2)	5 (4)	5 (3)	7 (6)	5 (1)
9 (2)	6 (0)	7 (6)	7 (5)	3 (9)	3 (2)	8 (10)	2 (2)	7 (5)	6 (3)
9 (3)	6 (2)	5 (6)	4 (6)	5 (5)	5 (0)	7 (9)	3 (3)	9 (4)	4 (2)
8 (4)	4 (4)	6 (8)	5 (7)	5 (2)	5 (9)	11 (5)	1 (5)	4 (5)	2 (5)

APPENDIX C

ANOVA COMPARING EFFECTIVENESS OF LIGHT TYPES IN EXCLUDING SHAD

(a) Illumination - 5 minutes

Degrees of Freedom	Mean Square	F-Ratio	Source
199			Total sum of squares
1			Correction due to a grand mean
198			Corrected total sum of squares
3	1025	11.06*	Lgt
4	459	4.95*	Rate
12	135	1.46	Lgt Rate*
179	092		Within cells

* Signal at $p < 0.01$

ANALYSIS OF VARIANCE TABLE

(b) Illumination - 15 minutes

Degrees of Freedom	Mean Square	F-Ratio	Source
199			Total sum of squares
1			Correction due to a grand mean
198			Corrected total sum of squares
3	3.32	4.98*	Lgt
4	2.07	3.11**	Rate
12	0.82	1.25	Lgt rate*
179	0.66		Within cells

* Signal at $p < 0.01$
**Signal at $p < 0.05$.

APPENDIX D

ANOVA COMPARING EFFECTIVENESS OF STROBE LIGHT IN EXCLUDING SHAD OVER 5 AND 15 MINUTE ILLUMINATION PERIODS

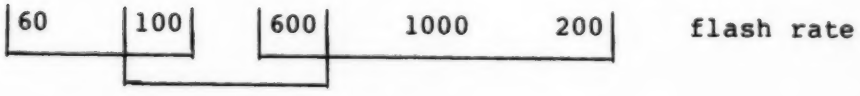
Analysis of Variance Table

Degrees of Freedom	Mean Square	F-Ratio	Source
100			Total sum of squares
1			Correction due to a grand mean of
99			Corrected total sum of squares
1	18.48	7.76*	Time
4	21.36	8.96*	Flash rate
	0.91	0.38	Time rate*
90	2.38		Within cells

* Signal at $p < 0.01$

Multiple Ranking

(lowest → highest effectiveness)



POOR

QUALITY

ORIGINAL